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**Jesionowski et al.**

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(54) **PLACEMENT OF DATA STORAGE CARTRIDGES IN SINGLE CARTRIDGE SLOTS AND IN MULTI-CARTRIDGE DEEP SLOT CELLS OF AN AUTOMATED DATA STORAGE LIBRARY**

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(75) Inventors: **Leonard George Jesionowski**, Tucson, AZ (US); **Shawn Michael Nave**, Tucson, AZ (US); **Raymond Yardy**, Tucson, AZ (US)

**OTHER PUBLICATIONS**

Author: Anonymous; Title: Automated Cartridge Disposition Promotion (Unloaded-Least Recently Used to Keep); Date: Aug. 1, 1993; Publisher: IBM Technical Disclosure Bulletin; vol. 36; Pertinent pp. 569-572; TDB-ACC-No. NN9608569.\*

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

Anonymous, Automated Cartridge Disposition Promotion (Unloaded-Least Recently Used to Keep) (TDB-AXX-No. NN9608569).\*

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 716 days.

\* cited by examiner

(21) Appl. No.: **12/200,689**

*Primary Examiner* — Gene Crawford

*Assistant Examiner* — Kyle Logan

(22) Filed: **Aug. 28, 2008**

(74) *Attorney, Agent, or Firm* — John H. Holcombe

(65) **Prior Publication Data**

US 2010/0058374 A1 Mar. 4, 2010

(57) **ABSTRACT**

(51) **Int. Cl.**  
**G09B 23/02** (2006.01)

In an automated data storage library having a plurality of multi-cartridge deep slot cells, each configured to store a plurality of data storage cartridges arranged in sequential order of tiers from front to rear; having a plurality of single cartridge storage slots; and having accessor(s) configured to selectively extract, place and transport cartridges with respect to the cells; operating the accessor(s) to selectively extract, place and transport data storage cartridges with respect to the multi-cartridge deep slot cells and the storage slots, and with respect to other elements of the automated data storage library; and, if a data storage cartridge is recently used by and is to be demounted from a selected other element of the automated data storage library: first, extracting another data storage cartridge from the storage slots, vacating one of the storage slots; and second, extracting, transporting and placing the demounted data storage cartridge in the vacated storage slot.

(52) **U.S. Cl.** ..... **700/214; 720/725**

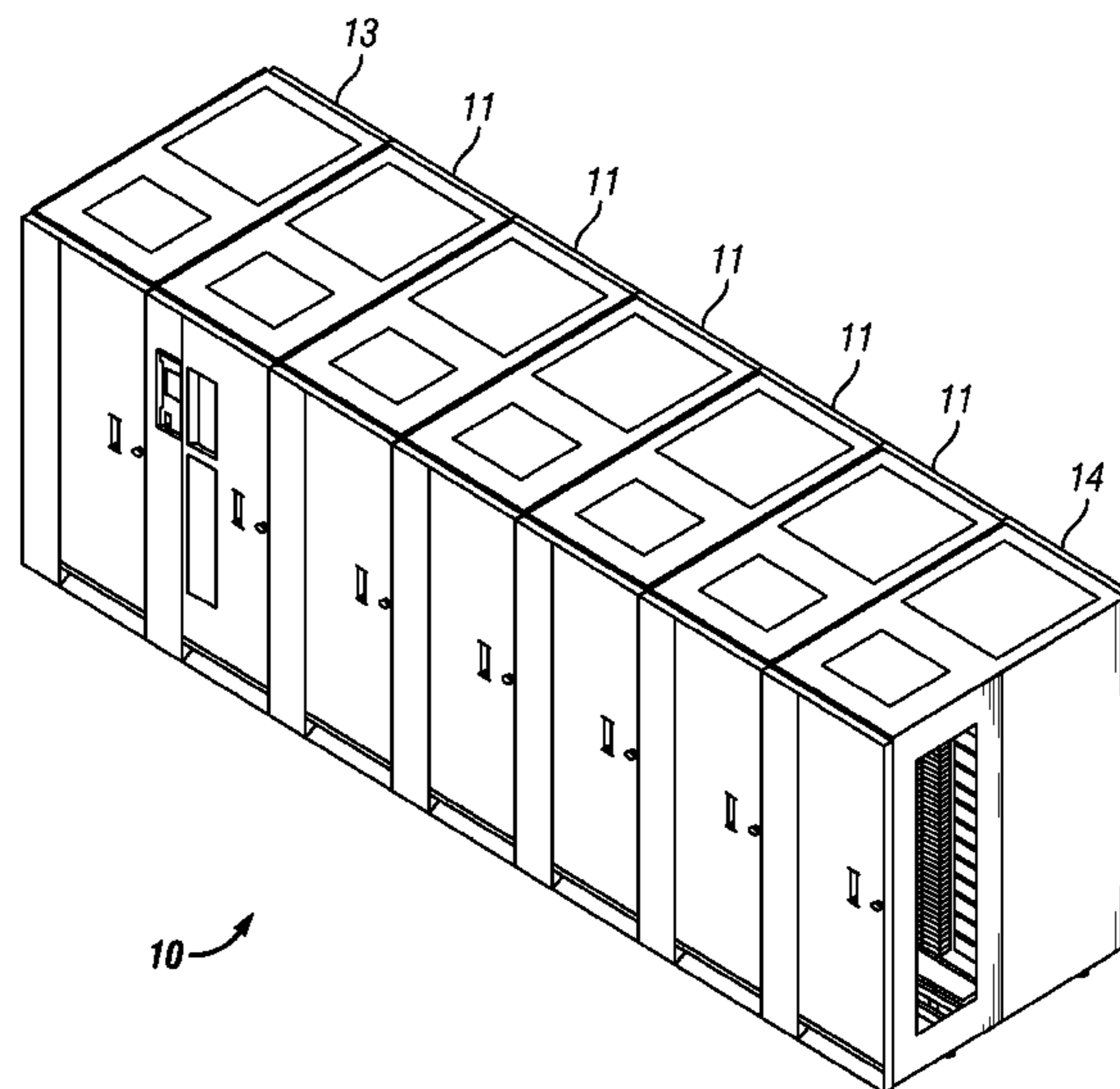
(58) **Field of Classification Search** ..... **700/214, 700/218, 228, 245; 369/30.28, 30.42, 30.48, 369/30.5, 30.55, 30.56, 30.6, 30.71, 30.86**  
See application file for complete search history.

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**4 Claims, 11 Drawing Sheets**



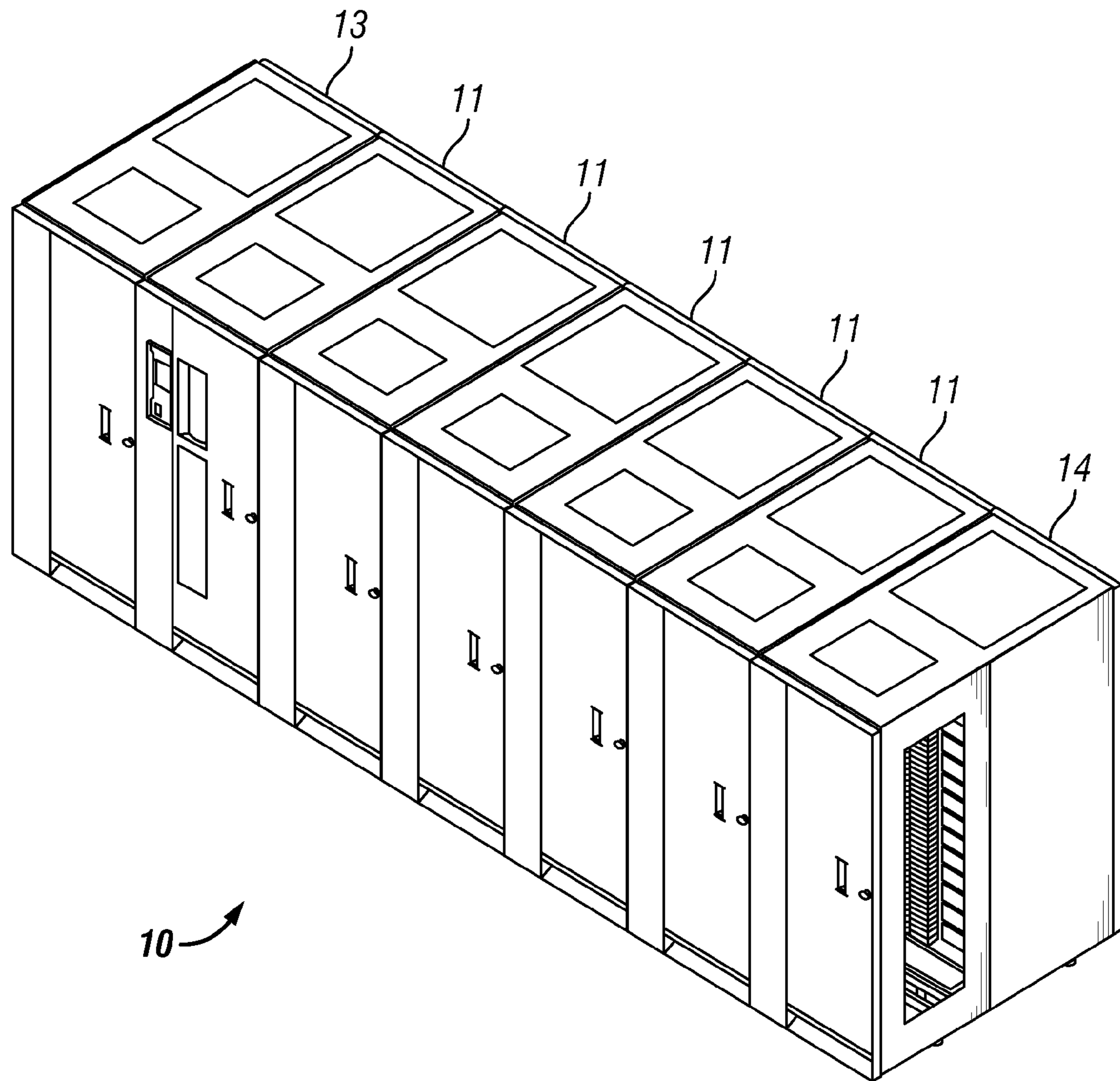


FIG. 1



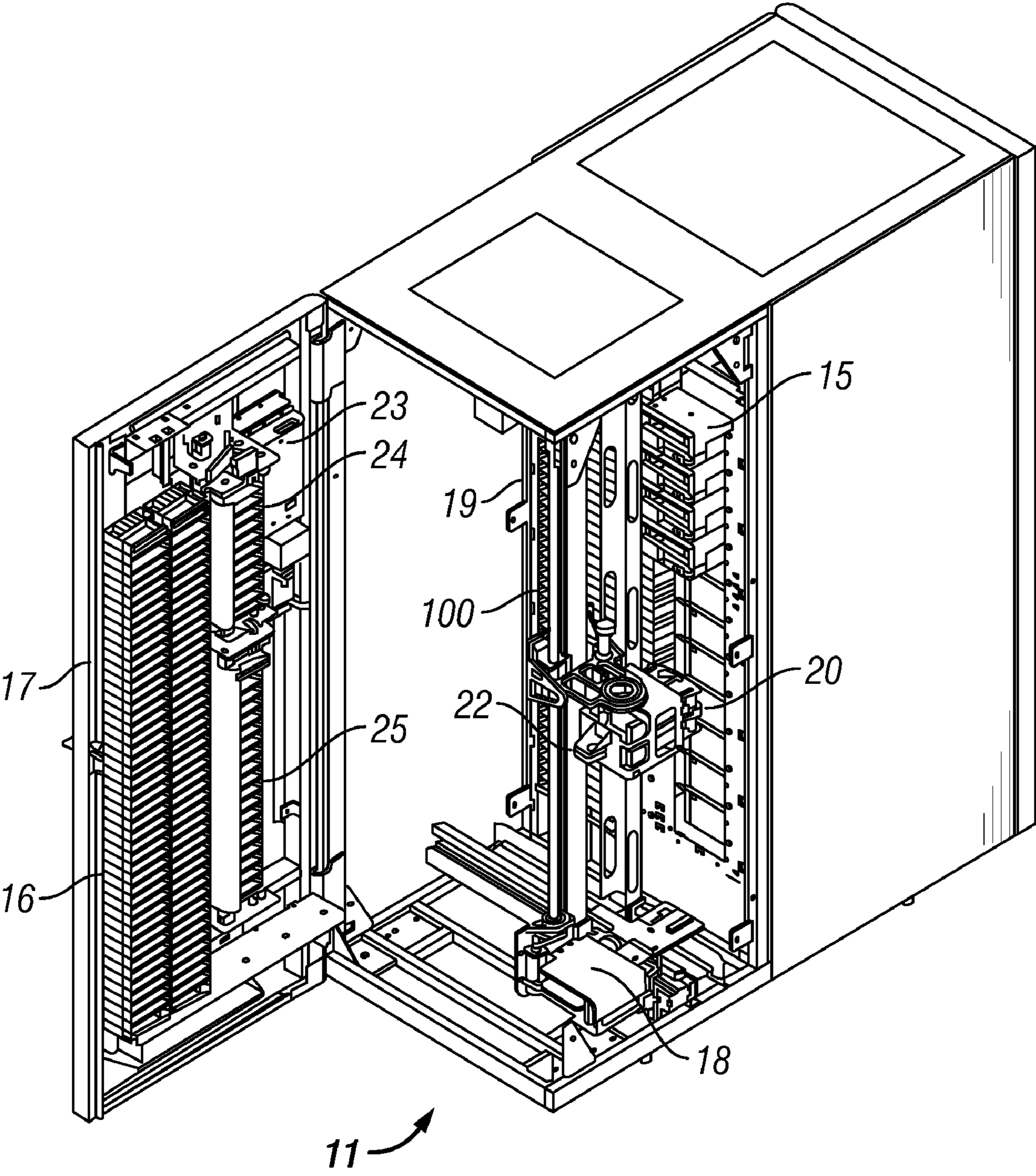


FIG. 2

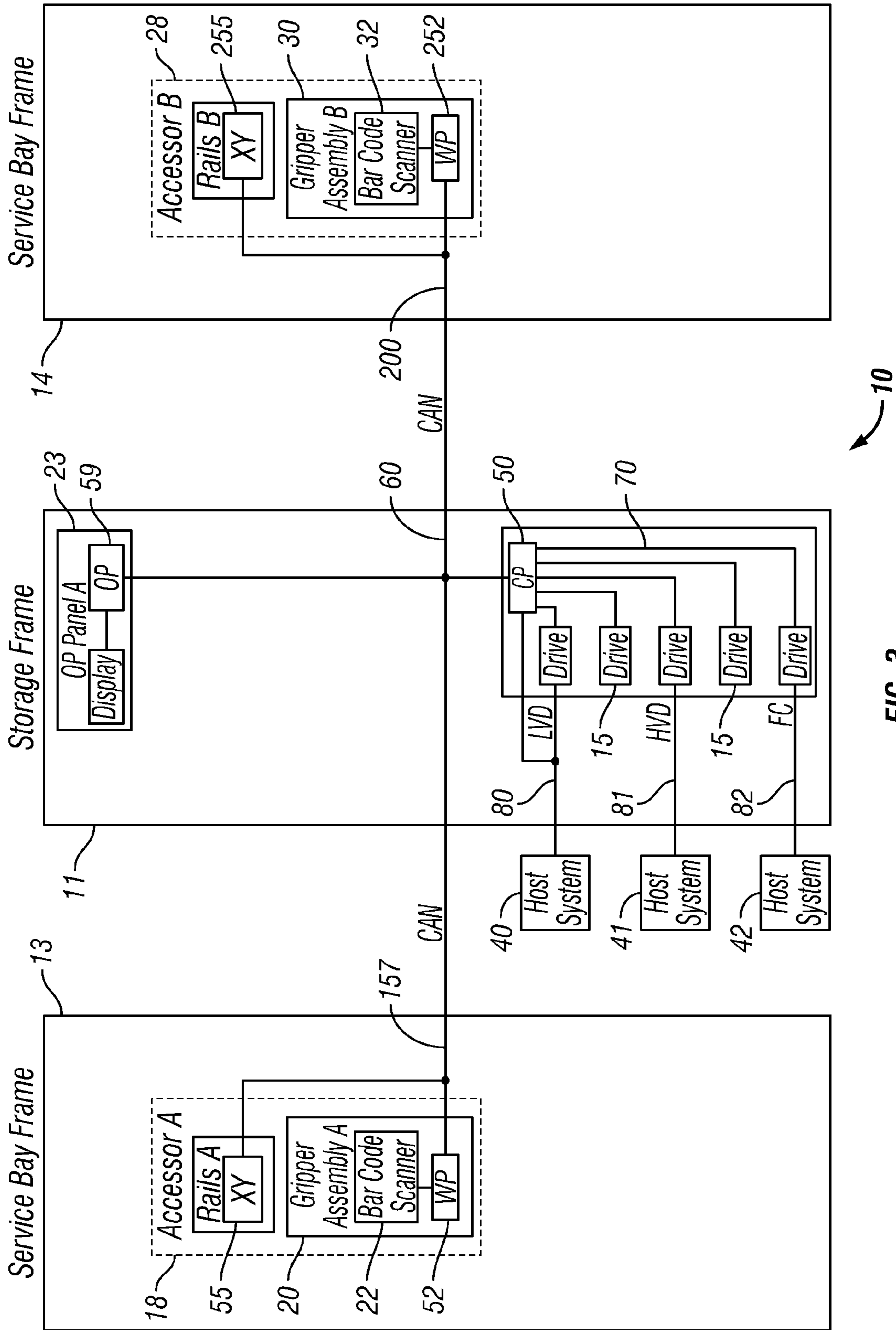
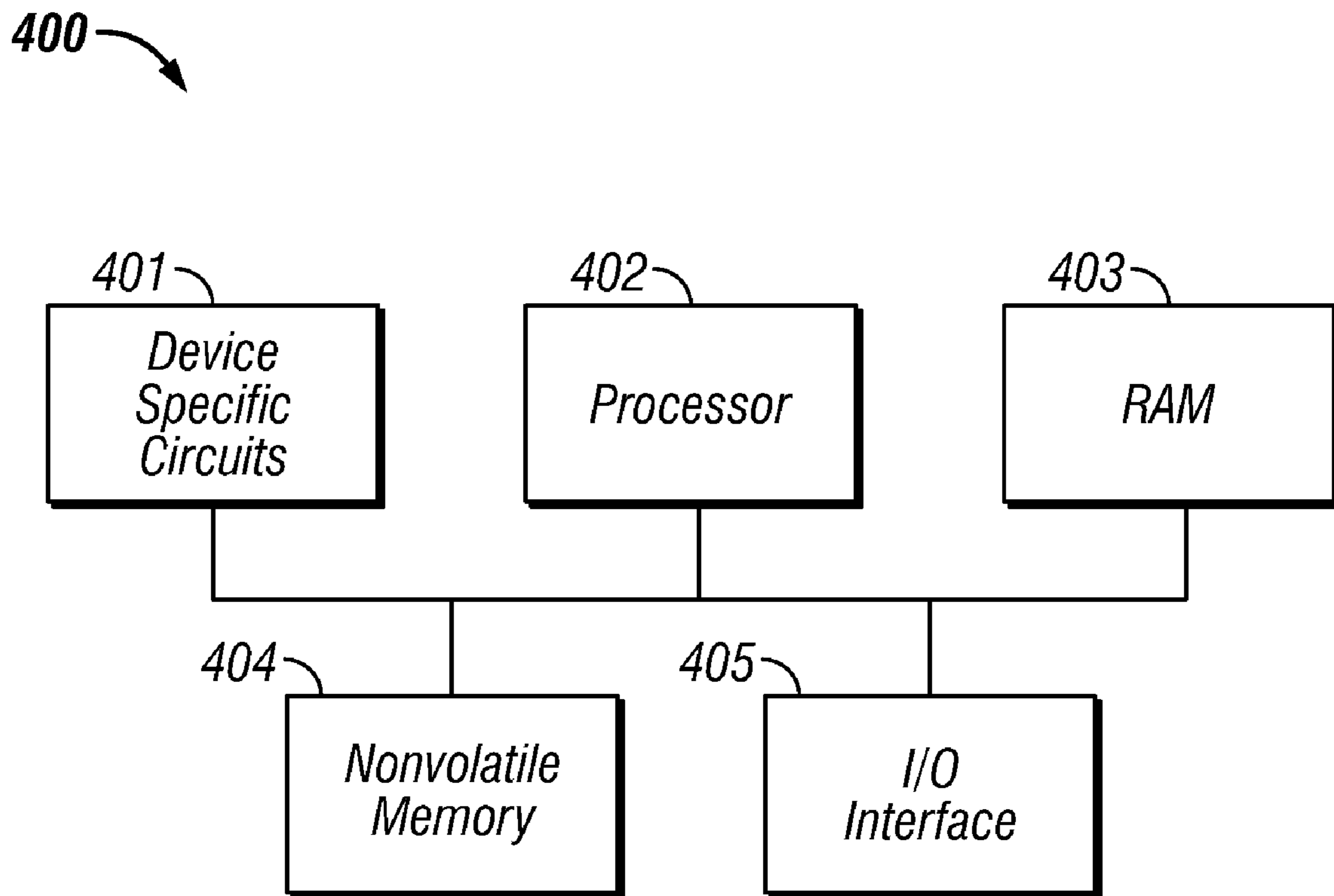


FIG. 3



**FIG. 4**

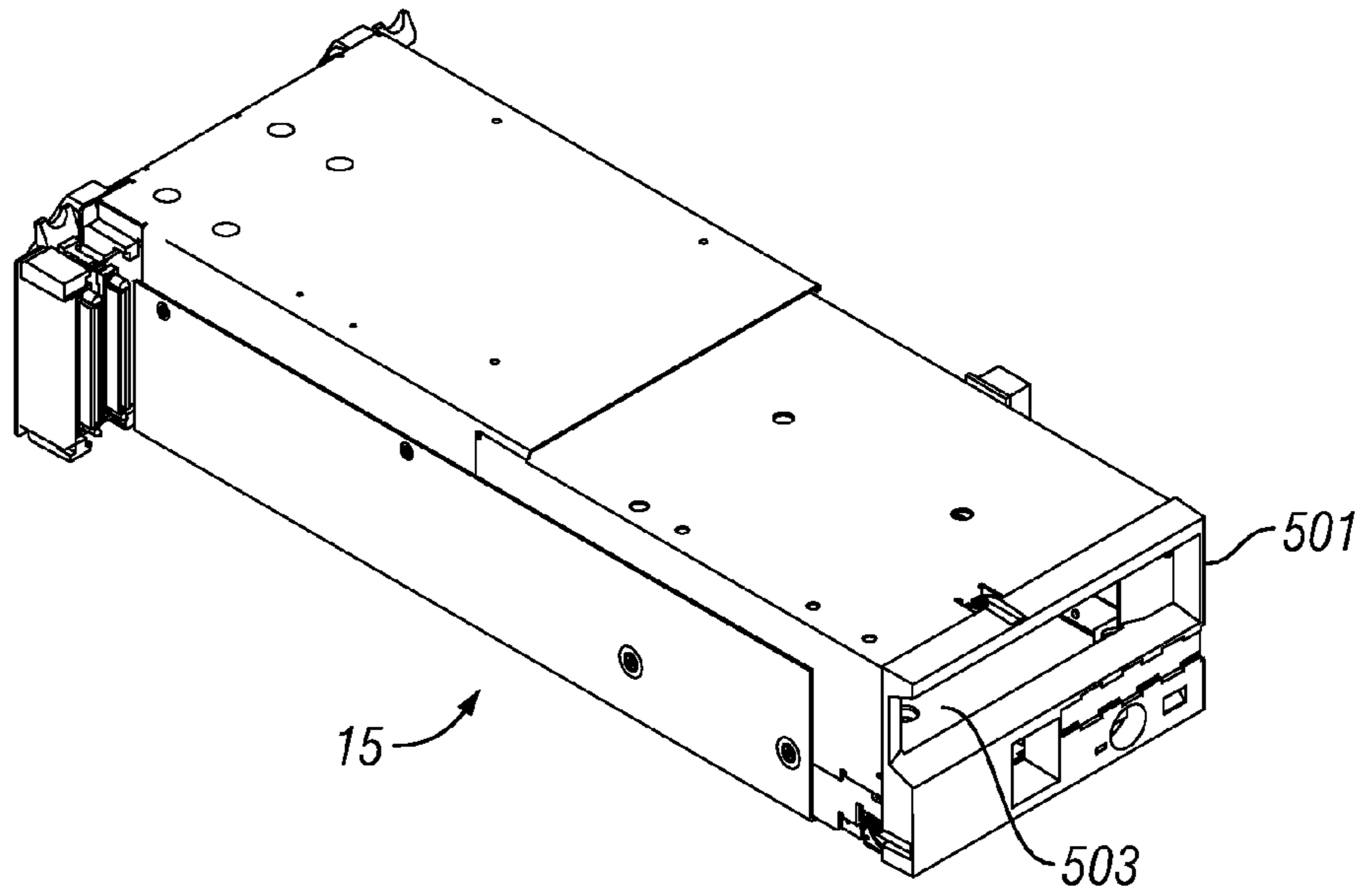


FIG. 5A

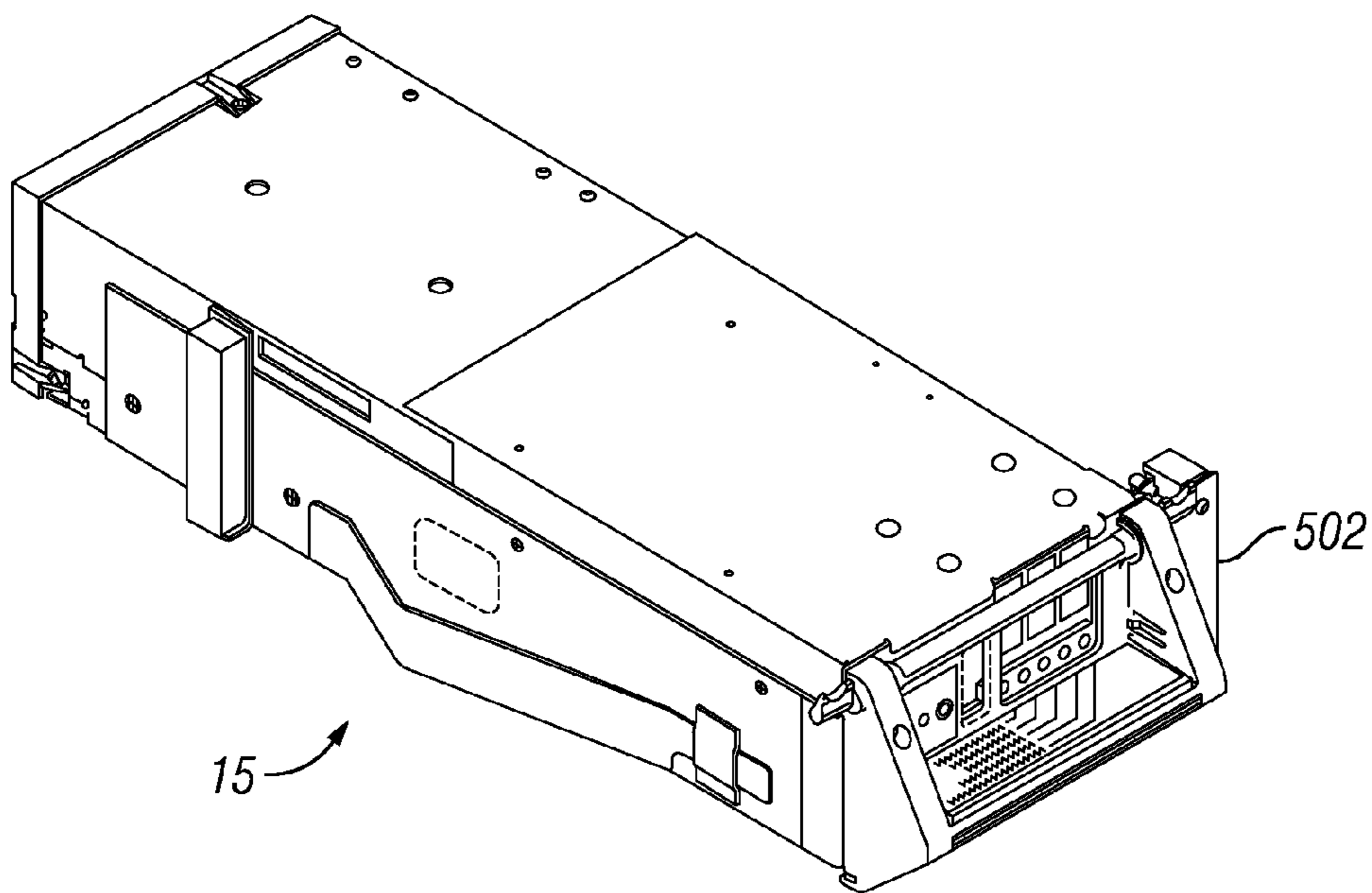


FIG. 5B

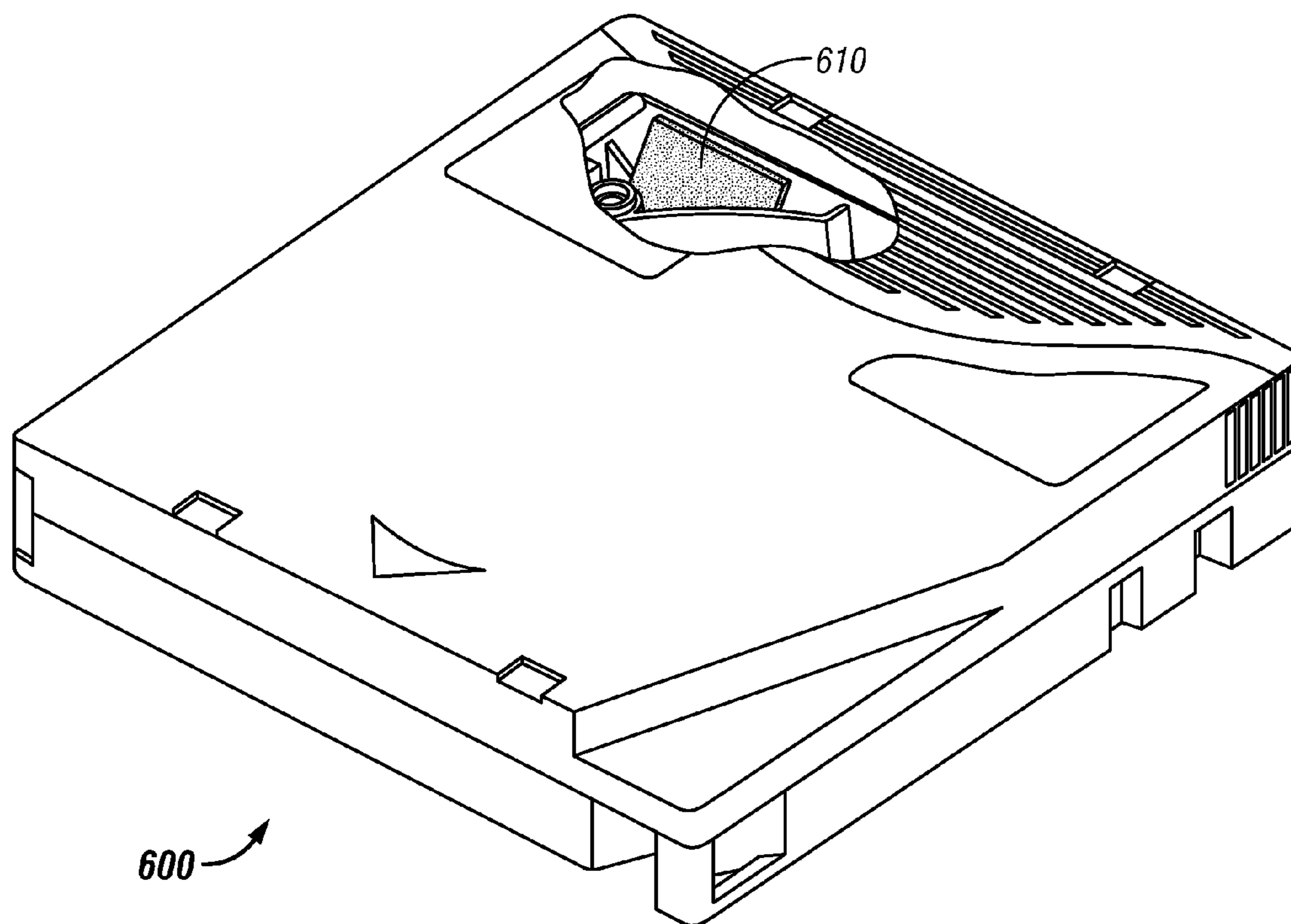


FIG. 6



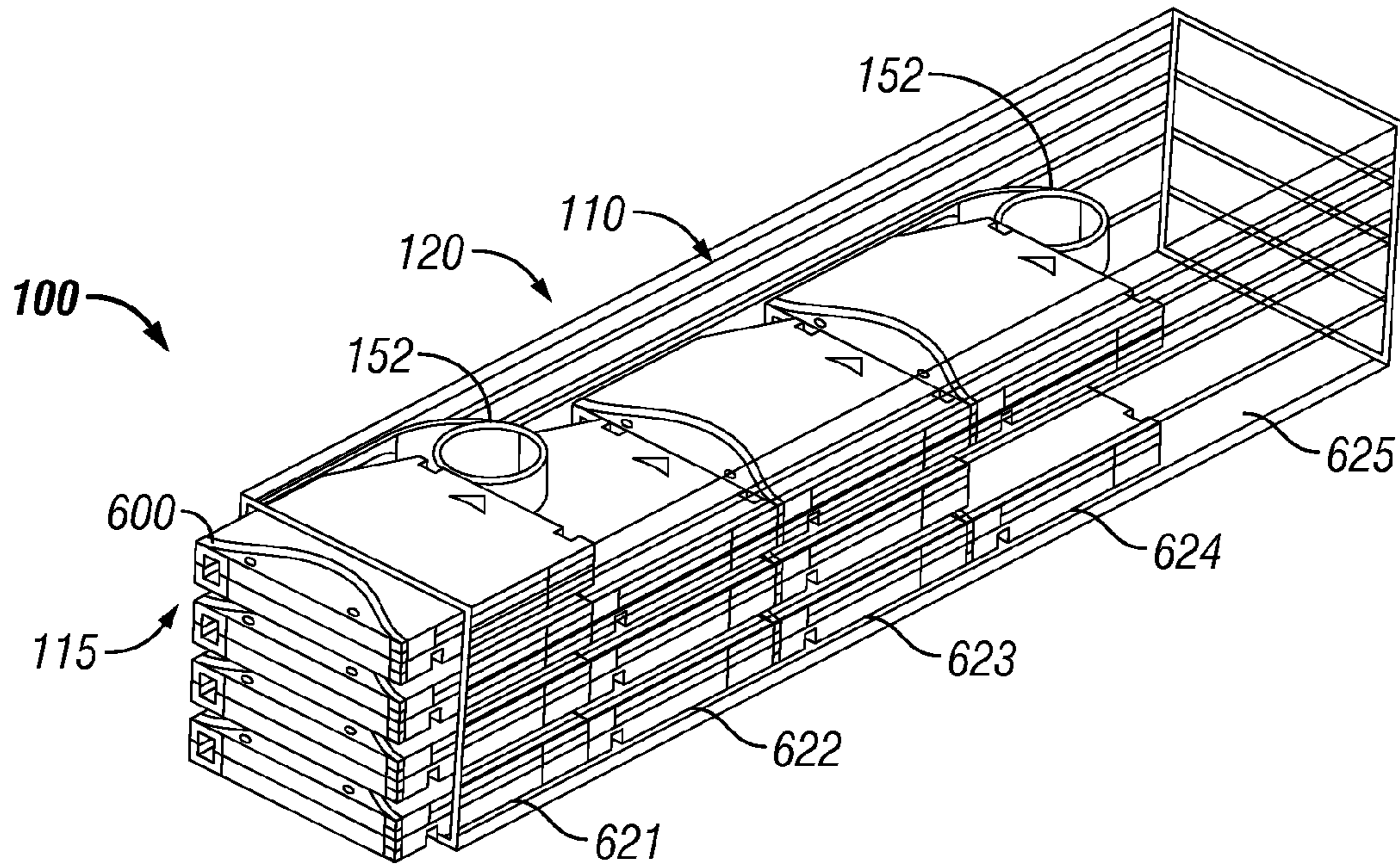


FIG. 7A

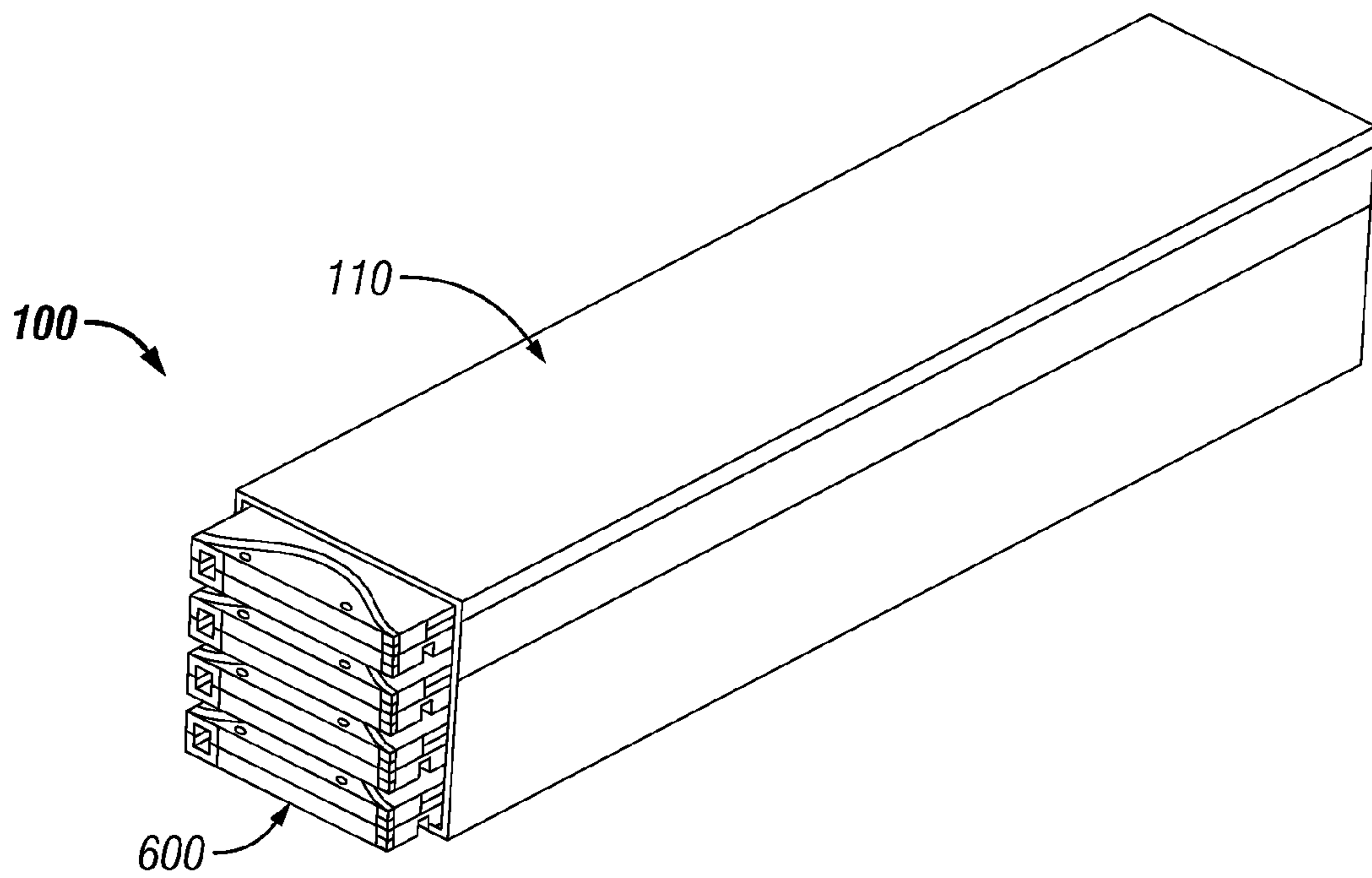


FIG. 7B



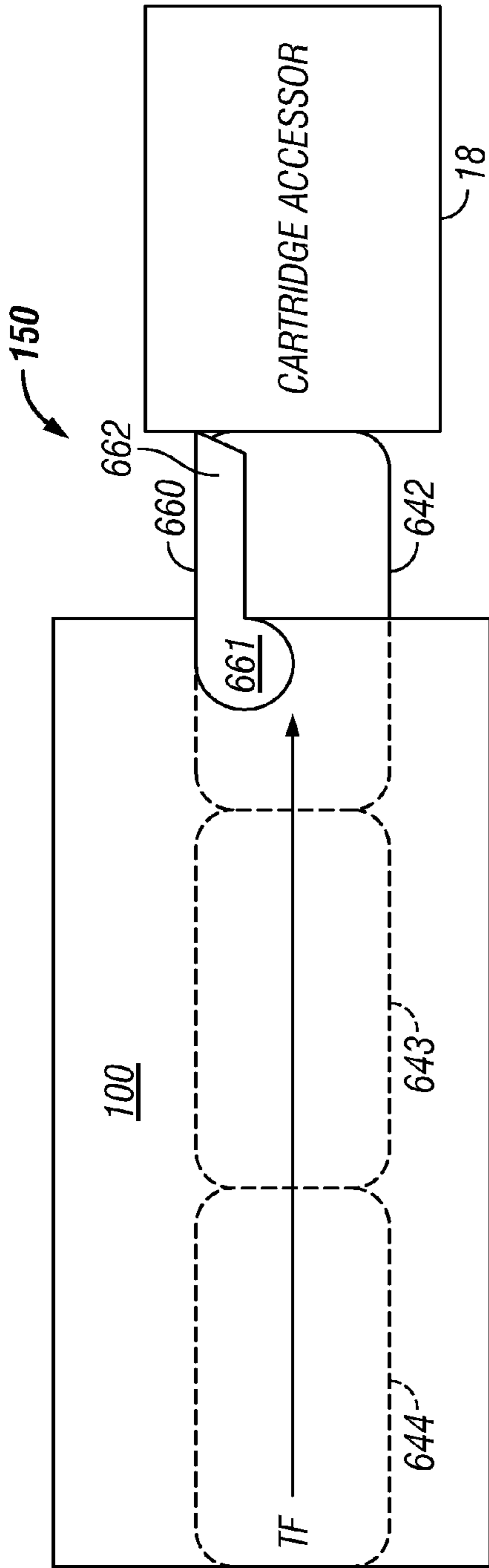


FIG. 8A

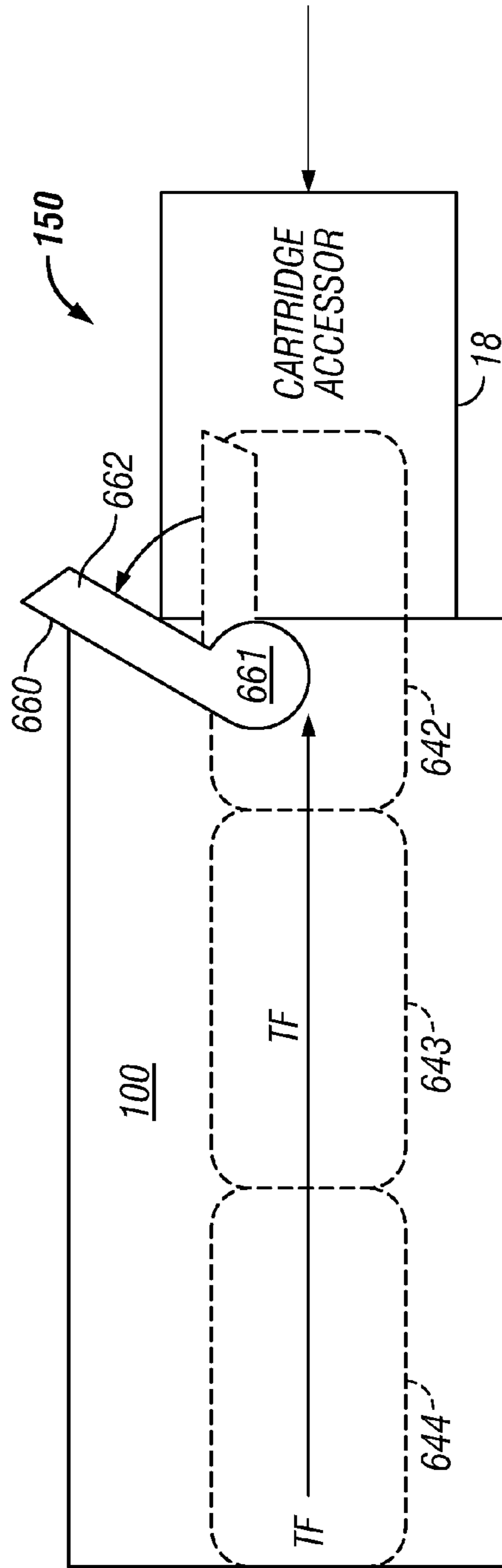


FIG. 8B

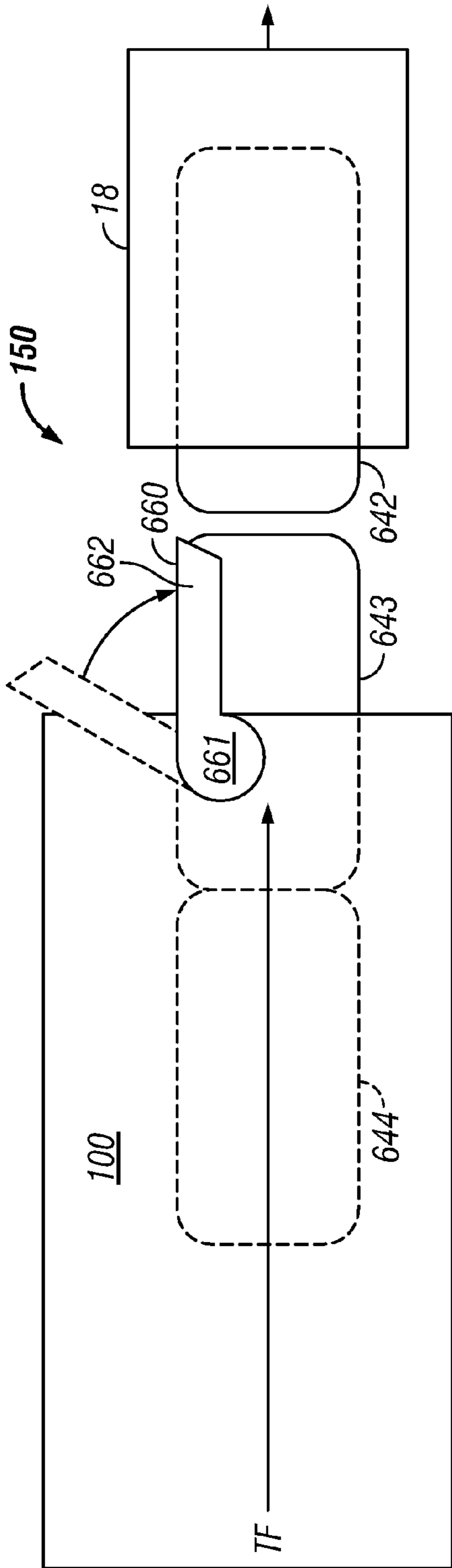


FIG. 8C

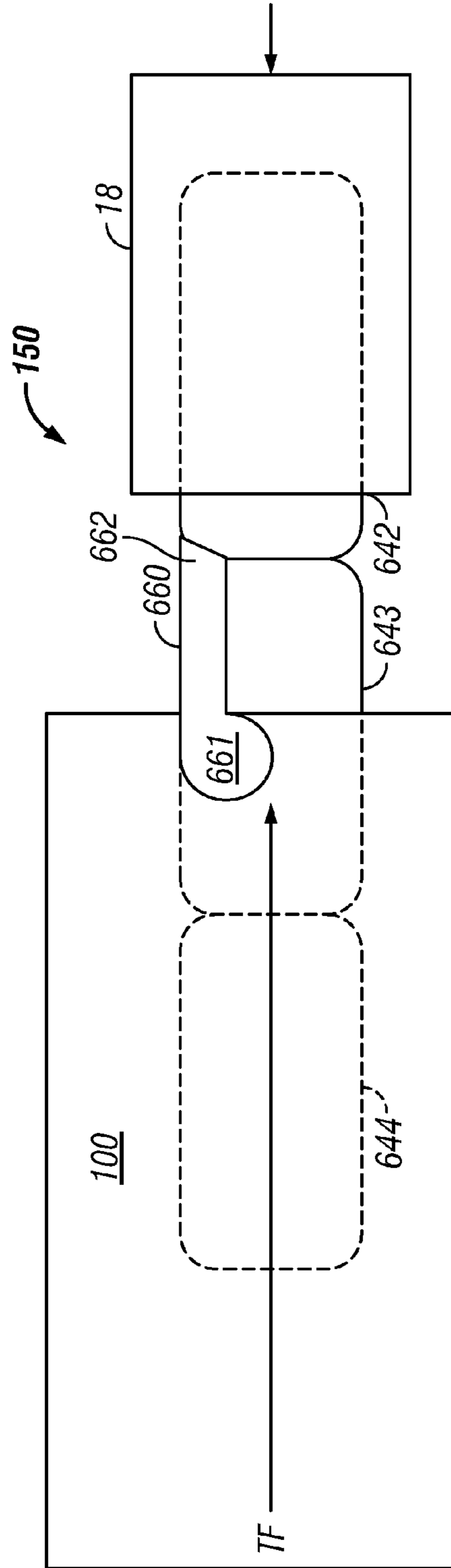


FIG. 8D

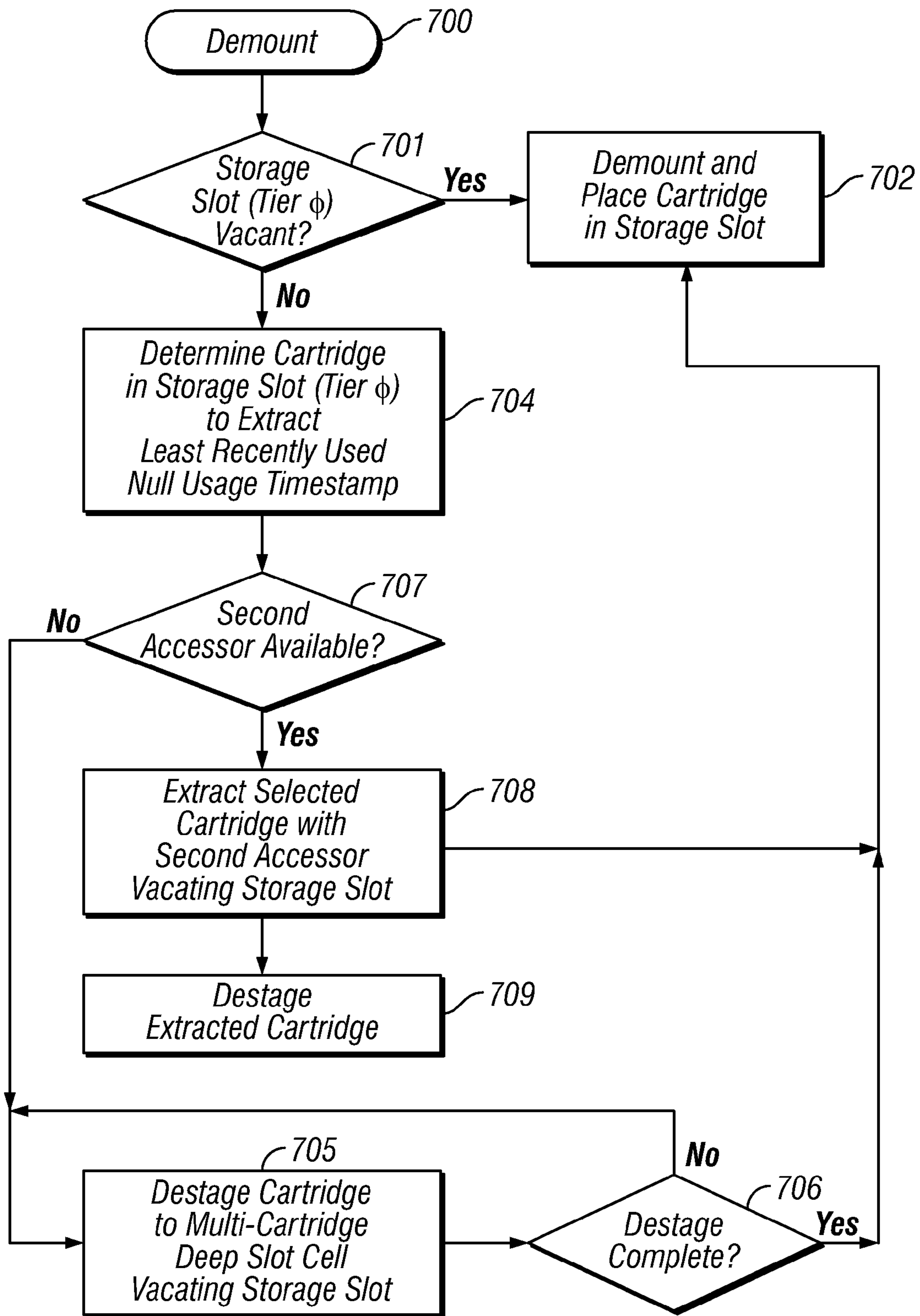


FIG. 9

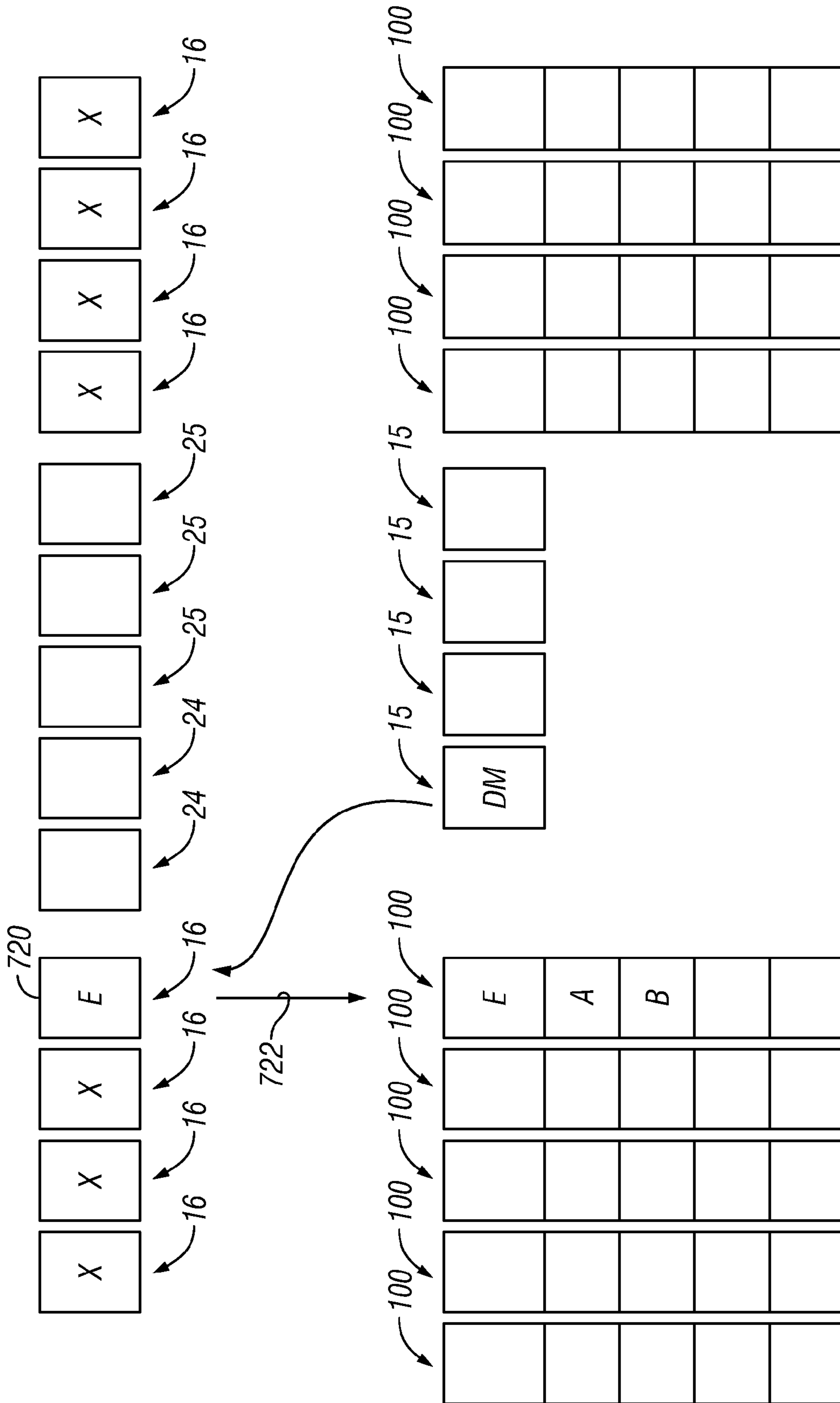


FIG. 10



1

**PLACEMENT OF DATA STORAGE  
CARTRIDGES IN SINGLE CARTRIDGE  
SLOTS AND IN MULTI-CARTRIDGE DEEP  
SLOT CELLS OF AN AUTOMATED DATA  
STORAGE LIBRARY**

DOCUMENT INCORPORATED BY REFERENCE

Commonly assigned U.S. patent application Ser. No. 12/200,713, and commonly assigned U.S. patent application Ser. No. 12/200,659, both filed on common date herewith, are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

The present invention generally relates to automated data storage libraries. More specifically, the invention relates to storage libraries with multi-cartridge deep slot cells.

BACKGROUND OF THE INVENTION

Automated data storage libraries are known for providing cost effective storage and retrieval of large quantities of data. The data in automated data storage libraries is typically stored on media of data storage cartridges that are, in turn, stored at storage slots or the like inside the library in a fashion that renders the media, and its resident data, accessible for physical retrieval. Such data storage cartridges are commonly termed "removable media." Data storage cartridge media may comprise any type of media on which data may be stored and which may serve as removable media, including but not limited to magnetic media (such as magnetic tape or disks), optical media (such as optical tape or disks), electronic media (such as PROM, EEPROM, flash PROM, CompactFlash™, Smartmedia™, Memory Stick™, etc.), or other suitable media. An example of a data storage cartridge that is widely employed in automated data storage libraries for mass data storage is a magnetic tape cartridge.

In addition to data storage media, automated data storage libraries typically comprise data storage drives that store data to, and/or retrieve data from, the data storage cartridge media. Further, automated data storage libraries typically comprise I/O stations at which data storage cartridges are supplied or added to, or removed from, the library. The transport of data storage cartridges between data storage slots, data storage drives, and I/O stations is typically accomplished by one or more accessors. Such accessors have grippers for physically retrieving the selected data storage cartridges from the storage slots within the automated data storage library and transporting such cartridges to the data storage drives by moving, for example, in the X and Y directions.

In an effort to increase storage capacity, deep slot technology allows for storage cells that contain more than a single data storage cartridge. Such storage libraries allow for higher density, or more cartridges stored per square foot. In 'deep slot' libraries, two or more cartridges may be stored in a multi-cartridge deep slot cell, arrayed in series, one behind the other, in tiers ranging from a frontmost tier to a rearmost tier.

Placing a data storage cartridge in a multi-cartridge deep slot cell results in moving any cartridge(s) already in the cell towards the rearmost tier, thereby "demoting" those cartridge(s). When the rearmost tier is filled with a cartridge, the entire deep slot cell is full.

Accessing a desired cartridge not at the frontmost tier thus requires removing cartridges stored in front of the desired cartridge, temporarily depositing the removed cartridge(s) at

2

some available storage, accessing the desired cartridge, and replacing the previously removed cartridge(s). As the result of removal of the accessed cartridge, the cartridges originally behind and remaining in the deep slot cell are "promoted" to positions closer to, or at the frontmost tier.

Accessing data storage cartridges from positions not at the frontmost tier tends to decrease the performance of the automated data storage library in accordance with the number of tiers of the position of the accessed cartridges from the frontmost tier.

SUMMARY OF THE INVENTION

Automated data storage libraries, and computer program products and methods for operating automated data storage libraries are provided.

In one embodiment, a method for operating an automated data storage library having at least a plurality of multi-cartridge deep slot cells, each configured to store up to a plurality of data storage cartridges arranged in sequential order of tiers from front to rear; having a plurality of single cartridge storage slots; and having at least one accessor configured to selectively extract, place and transport data storage cartridges with respect to the multi-cartridge deep slot cells, the method comprises the steps of:

operating at least one accessor to selectively extract, place and transport data storage cartridges with respect to the multi-cartridge deep slot cells and the storage slots, and with respect to other elements of the automated data storage library; and

in the selectively extracting, placing and transporting steps, if a data storage cartridge is recently used by a selected other element of the automated data storage library, and is to be demounted from the selected other element:

first, in the selectively extracting, placing and transporting steps, extracting another data storage cartridge from the storage slots, vacating one of the storage slots; and

second, in the selectively extracting, placing and transporting steps, extracting, transporting and placing the demounted data storage cartridge in the vacated storage slot.

In a further embodiment, the method comprises, in the first extracting another data storage cartridge step, extracting the least recently used data storage cartridge stored in the storage slots.

In another embodiment, the method comprises, in the first extracting another data storage cartridge step, extracting the data storage cartridge from a storage slot having the closest proximity to the source of the move of the demounted data storage cartridge.

In still another embodiment, wherein the data storage library comprises at least two the accessors configured to selectively extract, place and transport data storage cartridges with respect to the multi-cartridge deep slot cells and the storage slots, the method comprises operating one of the accessors to perform the first step and operating another of the accessors to perform the second step.

In another embodiment, the another data storage cartridge comprises a least recently used data storage cartridge stored in the storage slots.

In still another embodiment, the another data storage cartridge comprises a data storage cartridge having a null usage timestamp.

For a fuller understanding of the present invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of an automated data storage library adaptable to implement an embodiment of the present



3

invention, with the view specifically depicting a library having a left hand service bay, multiple storage frames and a right hand service bay;

FIG. 2 is an isometric view of an automated data storage library adaptable to implement an embodiment of the present invention, with the view specifically depicting an exemplary basic configuration of the internal components of a library;

FIG. 3 is a block diagram of an automated data storage library adaptable to implement an embodiment of the present invention, with the diagram specifically depicting a library that employs a distributed system of modules with a plurality of processor nodes;

FIG. 4 is a block diagram depicting an exemplary controller configuration;

FIG. 5 is an isometric view of the front and rear of a data storage drive of the automated data storage library of FIGS. 1, 2 and 3;

FIG. 6 is an isometric view of a data storage cartridge which may be stored by the automated data storage library of FIGS. 1, 2 and 3;

FIGS. 7A-7B illustrate one embodiment of a multi-cartridge deep slot cell of the automated data storage library of FIGS. 1, 2 and 3;

FIGS. 8A, 8B, 8C, 8D illustrate one embodiment of a cartridge blocking mechanism for the cell of FIGS. 7A, 7B;

FIG. 9 illustrates one embodiment of a method for storing cartridges in accordance with one aspect of the invention; and

FIG. 10 illustrates examples of operation of the method of FIG. 9 in the automated data storage library of FIGS. 1, 2 and 3.

#### DETAILED DESCRIPTION OF THE INVENTION

This invention is described in preferred embodiments in the following description with reference to the Figures, in which like numbers represent the same or similar elements. While this invention is described in terms of the best mode for achieving this invention's objectives, it will be appreciated by those skilled in the art that variations may be accomplished in view of these teachings without deviating from the spirit or scope of the invention.

The invention will be described as embodied in an automated magnetic tape library storage system for use in a data processing environment. Although the invention shown uses magnetic tape cartridges, one skilled in the art will recognize the invention equally applies to optical disk cartridges or other removable storage media and the use of either different types of cartridges or cartridges of the same type having different characteristics. Furthermore the description of an automated magnetic tape storage system is not meant to limit the invention to magnetic tape data processing applications as the invention herein can be applied to any media storage and cartridge handling systems in general.

FIGS. 1 and 2 illustrate an automated data storage library 10 which stores and retrieves data storage cartridges containing data storage media (not shown) at multi-cartridge deep slot cells 100 and single cartridge storage slots 16. It is noted that references to "data storage media" herein refer to data storage cartridges, and for purposes herein the two terms are used synonymously. An example of an automated data storage library which may implement the present invention, and has a configuration as depicted in FIGS. 1 and 2, is the IBM 3584 UltraScalable Tape Library. The library of FIG. 1 comprises a left hand service bay 13, one or more storage frames 11, and right hand service bay 14. As will be discussed, a frame may comprise an expansion component of the library. Frames may be added or removed to expand or reduce the size

4

and/or functionality of the library. Frames may comprise additional storage slots, deep slot cells, drives, import/export stations, accessors, operator panels, etc.

FIG. 2 shows an example of a storage frame 11, which is the base frame of the library 10 and is contemplated to be the minimum configuration of the library. In this minimum configuration, there is only a single accessor (i.e., there are no redundant accessors) and there is no service bay. The library 10 is arranged for accessing data storage media in response to commands from at least one external host system (not shown), and comprises a plurality of storage slots 16 on front wall 17 and a plurality of multi-cartridge deep slot cells 100 on rear wall 19, both for storing data storage cartridges that contain data storage media. The storage slots 16 are configured to store a single data storage cartridge, and the multi-cartridge deep slot cells 100 are configured to store a plurality of data storage cartridges arranged in sequential order of tiers from front to rear. The library also comprises at least one data storage drive 15 for reading and/or writing data with respect to the data storage media; and a first accessor 18 for transporting the data storage media between the plurality of storage slots 16, the multi-cartridge deep slot cells, and the data storage drive(s) 15. The data storage drives 15 may be optical disk drives or magnetic tape drives, or other types of data storage drives as are used to read and/or write data with respect to the data storage media. The storage frame 11 may optionally comprise an operator panel 23 or other user interface, such as a web-based interface, which allows a user to interact with the library. The storage frame 11 may optionally comprise an upper I/O station 24 and/or a lower I/O station 25, which allows data storage cartridges to be added to the library inventory and/or removed from the library without disrupting library operation. Herein, adding data storage cartridges to the library may also be called "inserting" data storage cartridges. The library 10 may comprise one or more storage frames 11, each having storage slots 16 accessible by first accessor 18.

As described above, the storage frames 11 may be configured with different components depending upon the intended function. One configuration of storage frame 11 may comprise storage slots 16 and/or multi-cartridge deep slot cells 100, data storage drive(s) 15, and other optional components to store and retrieve data from the data storage cartridges, and another storage frame 11 may comprise storage slots 16 and/or multi-cartridge deep slot cells 100 and no other components. The first accessor 18 comprises a gripper assembly 20 for gripping one or more data storage media and may include a bar code scanner 22 or other reading system, such as a cartridge memory reader or similar system, mounted on the gripper 20, to "read" identifying information about the data storage media.

FIG. 3 illustrates an embodiment of an automated data storage library 10 of FIGS. 1 and 2, which employs a controller arranged as a distributed system of modules with a plurality of processor nodes. An example of an automated data storage library which may implement the distributed system depicted in the block diagram of FIG. 3, and which implement the present invention, is the IBM 3584 UltraScalable Tape Library. For a fuller understanding of a distributed control system incorporated in an automated data storage library, refer to U.S. Pat. No. 6,356,803, which is entitled "Automated Data Storage Library Distributed Control System," which is incorporated herein for reference.

While the automated data storage library 10 has been described as employing a distributed control system, the present invention may be implemented in automated data storage libraries regardless of control configuration, such as,



but not limited to, an automated data storage library having one or more library controllers that are not distributed, as that term is defined in U.S. Pat. No. 6,356,803. The library of FIG. 3 comprises one or more storage frames 11, a left hand service bay 13 and a right hand service bay 14. The left hand service bay 13 is shown with a first accessor 18. As discussed above, the first accessor 18 comprises a gripper assembly 20 and may include a reading system 22 to “read” identifying information about the data storage media. The right hand service bay 14 is shown with a second accessor 28. The second accessor 28 comprises a gripper assembly 30 and may include a reading system 32 to “read” identifying information about the data storage media. In the event of a failure or other unavailability of the first accessor 18, or its gripper 20, etc., the second accessor 28 may perform some or all of the functions of the first accessor 18. The two accessors 18, 28 may share one or more mechanical paths or they may comprise completely independent mechanical paths. In one example, the accessors 18, 28 may have a common horizontal rail with independent vertical rails. The first accessor 18 and the second accessor 28 are described as first and second for descriptive purposes only and this description is not meant to limit either accessor to an association with either the left hand service bay 13, or the right hand service bay 14.

In the exemplary library, first accessor 18 and second accessor 28 move their grippers in at least two directions, called the horizontal “X” direction and vertical “Y” direction, to retrieve and grip, or to deliver and release the data storage cartridge at the storage slots 16 and multi-cartridge deep slot cells 100, and to mount and demount the data storage cartridge at the data storage drives 15.

The exemplary library 10 receives commands from one or more host systems 40, 41 or 42. The host systems, such as host servers, communicate with the library directly, e.g., on path 80, through one or more control ports (not shown), or through one or more data storage drives 15 on paths 81, 82, providing commands to access particular data storage cartridges and move the cartridges, for example, between the storage slots 16 and the data storage drives 15. The commands are typically logical commands identifying the cartridges or cartridge media and/or logical locations for accessing the media. The terms “commands” and “work requests” are used interchangeably herein to refer to such communications from the host system 40, 41 or 42 to the library 10 as are intended to result in accessing particular data storage media within the library 10.

The exemplary library is controlled by a library controller, which in one embodiment comprises a distributed control system receiving the logical commands from hosts, determining the required actions, and converting the actions to physical movements of first accessor 18 and/or second accessor 28.

In the exemplary library, the distributed control system comprises a plurality of processor nodes, each having one or more computer processors. In one example of a distributed control system, a communication processor node 50 may be located in a storage frame 11. The communication processor node provides a communication link for receiving the host commands, either directly or through the drives 15, via at least one external interface, e.g., coupled to line 80.

The communication processor node 50 may additionally provide a communication link 70 for communicating with the data storage drives 15. The communication processor node 50 may be located in the frame 11, close to the data storage drives 15. Additionally, in an example of a distributed processor system, one or more additional work processor nodes are provided, which may comprise, e.g., a work processor node 52 that may be located at first accessor 18, and that is coupled

to the communication processor node 50 via a network 60, 157. Each work processor node may respond to received commands that are broadcast to the work processor nodes from any communication processor node, and the work processor nodes may also direct the operation of the accessors, providing move commands. An XY processor node 55 may be provided and may be located at an XY system of first accessor 18. The XY processor node 55 is coupled to the network 60, 157, and is responsive to the move commands, operating the XY system to position the gripper 20.

Also, an operator panel processor node 59 may be provided at the optional operator panel 23 for providing an interface for communicating between the operator panel and the communication processor node 50, the work processor nodes 52, 252, and the XY processor nodes 55, 255.

A network, for example comprising a common bus 60, is provided, coupling the various processor nodes. The network may comprise a robust wiring network, such as the commercially available CAN (Controller Area Network) bus system, which is a multi-drop network, having a standard access protocol and wiring standards, for example, as defined by CiA, the CAN in Automation Association, Am Weich Selgarten 26, D-91058 Erlangen, Germany. Other networks, such as Ethernet, or a wireless network system, such as RF or infrared, may be employed in the library as is known to those of skill in the art. In addition, multiple independent networks may also be used to couple the various processor nodes.

The communication processor node 50 is coupled to each of the data storage drives 15 of a storage frame 11, via lines 70, communicating with the drives and with host systems 40, 41 and 42. Alternatively, the host systems may be directly coupled to the communication processor node 50, at input 80 for example, or to control port devices (not shown) which connect the library to the host system(s) with a library interface similar to the drive/library interface. As is known to those of skill in the art, various communication arrangements may be employed for communication with the hosts and with the data storage drives. In the example of FIG. 3, host connections 80 and 81 are SCSI busses. Bus 82 comprises an example of a Fibre Channel bus which is a high speed serial data interface, allowing transmission over greater distances than the SCSI bus systems.

The data storage drives 15 may be in close proximity to the communication processor node 50, and may employ a short distance communication scheme, such as SCSI, or a serial connection, such as RS-422. The data storage drives 15 are thus individually coupled to the communication processor node 50 by means of lines 70. Alternatively, the data storage drives 15 may be coupled to the communication processor node 50 through one or more networks, such as a common bus network.

Additional storage frames 11 may be provided and each is coupled to the adjacent storage frame. Any of the storage frames 11 may comprise communication processor nodes 50, storage slots 16, data storage drives 15, and networks 60.

Further, as described above, the automated data storage library 10 may comprise a plurality of accessors. A second accessor 28, for example, is shown in a right hand service bay 14 of FIG. 3. The second accessor 28 may comprise a gripper 30 for accessing the data storage media, and an XY system 255 for moving the second accessor 28. The second accessor 28 may run on the same horizontal mechanical path as first accessor 18, or on an adjacent path. The exemplary control system additionally comprises an extension network 200 forming a network coupled to network 60 of the storage frame(s) 11 and to the network 157 of left hand service bay 13.



In FIG. 3 and the accompanying description, the first and second accessors are associated with the left hand service bay 13 and the right hand service bay 14 respectively. This is for illustrative purposes and there may not be an actual association. In addition, network 157 may not be associated with the left hand service bay 13 and network 200 may not be associated with the right hand service bay 14. Depending on the design of the library, it may not be necessary to have a left hand service bay 13 and/or a right hand service bay 14.

An automated data storage library 10 typically comprises one or more controllers to direct the operation of the automated data storage library. Host computers and data storage drives typically comprise similar controllers. A library controller may take many different forms and may comprise, for example but not limited to, an embedded system, a distributed control system, a personal computer, or a workstation. Essentially, the term "library controller" as used herein is intended in its broadest sense as a device that contains at least one computer processor, as such term is defined herein. FIG. 4 shows a typical controller 400 with a processor 402, RAM (Random Access Memory) 403, nonvolatile memory 404, device specific circuits 401, and I/O interface 405. Alternatively, the RAM 403 and/or nonvolatile memory 404 may be contained in the processor 402 as could the device specific circuits 401 and I/O interface 405. The processor 402 may comprise, for example, an off-the-shelf microprocessor, custom processor, FPGA (Field Programmable Gate Array), ASIC (Application Specific Integrated Circuit), discrete logic, or the like. The RAM (Random Access Memory) 403 is typically used to hold variable data, stack data, executable instructions, and the like. The nonvolatile memory 404 may comprise any type of nonvolatile memory such as, but not limited to, EEPROM (Electrically Erasable Programmable Read Only Memory), flash PROM (Programmable Read Only Memory), battery backup RAM, and hard disk drives. The nonvolatile memory 404 is typically used to hold the executable firmware and any nonvolatile data. The I/O interface 405 comprises a communication interface that allows the processor 402 to communicate with devices external to the controller. Examples may comprise, but are not limited to, serial interfaces such as RS-232, USB (Universal Serial Bus) or SCSI (Small Computer Systems Interface). The device specific circuits 401 provide additional hardware to enable the controller 400 to perform unique functions such as, but not limited to, motor control of a cartridge gripper. The device specific circuits 401 may comprise electronics that provide, by way of example but not limitation, Pulse Width Modulation (PWM) control, Analog to Digital Conversion (ADC), Digital to Analog Conversion (DAC), etc. In addition, all or part of the device specific circuits 401 may reside outside the controller 400.

While the automated data storage library 10 is described as employing a distributed control system, the present invention may be implemented in various automated data storage libraries regardless of control configuration, such as, but not limited to, an automated data storage library having one or more library controllers that are not distributed. A library controller may comprise one or more dedicated controllers of a prior art library. For example, there may be a primary controller and a backup controller. In addition, a library controller may comprise one or more processor nodes of a distributed control system. For example, communication processor node 50 (FIG. 3) may comprise the library controller while the other processor nodes (if present) may assist the library controller and/or may provide backup or redundant functionality. In another example, communication processor node 50 and work processor node 52 may work cooperatively to comprise

the library controller while the other processor nodes (if present) may assist the library controller and/or may provide backup or redundant functionality. Still further, all of the processor nodes may comprise the library controller. Herein, library controller may comprise a single processor or controller or it may comprise multiple processors or controllers.

FIGS. 5A and 5B illustrate an embodiment of the front 501 and rear 502 of a data storage drive 15. In the example, the data storage drive 15 comprises a hot-swap drive canister. This is only an example and is not meant to limit the invention to hot-swap drive canisters. In fact, any configuration of data storage drive may be used whether or not it comprises a hot-swap canister. A data storage cartridge may be placed into the data storage drive 15 at opening 503. As discussed above, a data storage drive 15 is used to read and/or write data with respect to the data storage media, and may additionally communicate with a memory which is separate from the media and is located within the cartridge.

FIG. 6 illustrates an embodiment of a data storage cartridge 600 with a cartridge memory 610 shown in a cutaway portion of the Figure. This is only an example and is not meant to limit the invention to cartridge memories. In fact, any configuration of data storage cartridge may be used whether or not it comprises a cartridge memory. Media of the data storage cartridge may comprise any type of media on which data may be stored, including but not limited to magnetic media (such as magnetic tape or disks), optical media (such as optical tape or disks), electronic media (such as PROM, EEPROM, flash PROM, CompactFlash™, Smartmedia™, Memory Stick™, etc.), or other suitable media. An example of a data storage cartridge that is widely employed in automated data storage libraries for mass data storage is a magnetic tape cartridge in which the media is magnetic tape.

FIGS. 7A and 7B illustrate one embodiment of a multi-cartridge deep slot cell 100 that may be employed in accordance with the present invention, and FIGS. 8A, 8B, 8C and 8D illustrate an embodiment of a retaining gate cartridge blocking mechanism 150 that retains the data storage cartridges in the multi-cartridge deep slot cell 100. Multi-cartridge deep slot cell 100 comprises a housing 110 defining an interior space 115. A plurality of storage slots 120 are disposed within the housing, and are, in one embodiment, configured for storing up to a plurality of data storage cartridges 600.

Alternatively, the multi-cartridge deep slot cell 100 is built into the frame of the automated data storage library.

In one embodiment, the retaining gate is externally attached to a multi-cartridge deep slot cell 100 relative to a front opening of the multi-cartridge deep slot cell 100 whereby the retaining gate can be activated by an accessor of an automated tape library. The retaining gate allows for positive cartridge retention against the pressure of biasing springs 152, and ensures that one or more data storage cartridges do not get pushed out of the multi-cartridge deep slot cell 100 simultaneously while allowing the pushing mechanism of the multi-cartridge deep slot cell 100 to always push the data storage cartridge(s) to the opening in a multi-cartridge deep slot cell 100. The accessor opens the retaining gate to gain access to the data storage cartridge in tier 1 and, upon its extraction, the biasing spring 152 moves the cartridge(s) behind the extracted cartridge forward, promoting the cartridge(s) by one tier.

The basic working of the retaining gate is that the gate prevents the data storage cartridge(s) from being pushed out of a multi-cartridge deep slot cell 100. For example, as shown in FIGS. 8A, 8B, 8C and 8D, a retaining gate 660 can be lifted by, for example, accessor 18 or by a front cartridge 642 for



cartridge removal from/insertion into a multi-cartridge deep slot cell **100**. Specifically, retaining gate **660** has a pivoting arm **661** mounted on multi-cartridge deep slot cell **100** via a pivoting post (not shown) that can be integral to a construction of multi-cartridge deep slot cell **100**. Pivoting arm **661** is located below a catch **662** of retaining gate **660** whereby a thrust force TF through data storage cartridge **644-642** by the pushing mechanism (not shown) of multi-cartridge deep slot cell **100** causes retaining gate **660** to stay closed in a retaining position as shown in FIG. **8A**. Retaining gate **660** is biased such that it closes in the downward direction over the front opening of multi-cartridge deep slot cell **100**. This constant biasing can be done by gravity as shown in FIG. **8A** or by a spring force attached to retaining gate **660** (not shown).

For removal of front tape cartridge **642** by accessor **18** from multi-cartridge deep slot cell **100**, retaining gate **660** must be lifted upward to a releasing position whereby catch **662** of retaining gate **660** is disengaged from front storage cartridge **642**. This can be seen in FIG. **8B** where accessor **18** interfaces with retaining gate **660** by providing a lifting force. Once retaining gate **660** is lifted to the releasing position and accessor **18** is engaged with storage cartridge **642**, accessor **18** can pull storage cartridge **642** out of multi-cartridge deep slot cell **100** and into accessor **18** without any interference of retaining gate **660** as shown in FIG. **8C**. In view of storage cartridges **644** and **643** being stored in multi-cartridge deep slot cell **100**, retaining gate **660** must return to its retaining position to prevent storage cartridges **644** and **643** from being ejected from multi-cartridge deep slot cell **100** by the pushing mechanism. During extraction of front tape cartridge **642** through the front opening of multi-cartridge deep slot cell **100**, retaining gate **660** which is being biased downward moves back to the retaining position to engage storage cartridge **643**.

Once front tape cartridge **642** is extracted and storage cartridges **643** and **644** are retained from being pushed out of multi-cartridge deep slot cell **100**, retaining gate **660** has successfully completed its cartridge retrieval process. Now retaining gate **660** must demonstrate an ability to work for cartridge insertion into multi-cartridge deep slot cell **100**. When accessor **18** begins to insert storage cartridge **642** back into multi-cartridge deep slot cell **100**, retaining gate **660** must be lifted to its releasing position in order to allow storage cartridge **642** through the front opening of multi-cartridge deep slot cell **100**. Catch **662** of retaining gate **660** interfaces with a rear portion of storage cartridge **642**, in particular a beveled surface of catch **662** as shown in FIG. **8D**, whereby retaining gate **660** is lifted to its releasing position as shown in FIG. **8B** due to storage cartridge **642** being pushed in multi-cartridge deep slot cell **100** by accessor **18**. In doing this operation, storage cartridges **644** and **643** are pushed deeper into multi-cartridge deep slot cell **100** by storage cartridge **642** in multi-cartridge deep slot cell **100** by accessor **18**. Upon full insertion into multi-cartridge deep slot cell **100**, retaining gate **660** moves to its retaining position to engage storage cartridge **642** as shown in FIG. **8A**.

For a fuller understanding of the retaining gate, refer to U.S. patent application Ser. No. 11/674,904, which is entitled "Retaining Gate for Deep Storage Slot Retention of Storage Cartridges", which is incorporated herein for reference.

Access to a storage slot may include the ability to remove a cartridge from a storage slot, the ability to place a cartridge into a storage slot, or combinations thereof.

In this example, the storage slots from top to bottom are considered to be in parallel and comprise the same tier. The storage slots from front to back, in one particular row, are considered to be in series and comprise sequential tiers.

Storage slots **120** are, in one embodiment, configured for storing up to a plurality of data storage cartridges **600**, arranged in sequential order of tiers **621**, **622**, **623**, **624** and **625** from front to rear. Herein, the frontmost tier **621** is also called "tier **1**", the next tier **622** is called "tier **2**", etc., and the last tier **625** is also called the "rearmost" tier.

Referring to FIG. **2**, in one embodiment, the single cartridge storage slots **16** are also termed "tier **0**".

Referring to FIGS. **1**, **2** and **3**, in one embodiment, the controller of automated data storage library **10** operates the accessor(s) **18**, **28** to selectively extract, place and transport data storage cartridges with respect to the multi-cartridge deep slot cells **100** and with respect to other elements of the automated data storage library, for example, extracting a cartridge from a multi-cartridge deep slot cell **100**, transporting the cartridge to a data storage drive **15** and placing the cartridge in the drive. The controller may then extract the cartridge from the data storage drive **15**, and the controller will direct the accessor to transport the cartridge to a specific multi-cartridge deep slot cell **100**, and place the cartridge in the specific multi-cartridge deep slot cell.

In one embodiment, one or more data storage cartridges may be added (also called inserted) into the library, for example, at an I/O station **24**, **25**. The controller of automated data storage library **10** operates the accessor(s) **18**, **28** to transport the cartridge(s) to specific multi-cartridge deep slot cell(s) **100**, and place the cartridge(s) in the specific multi-cartridge deep slot cell(s).

Similarly, the controller may also operate the accessor(s) to selectively extract, place and transport data storage cartridges with respect to the single cartridge storage slots **16**, and to transport inserted or added cartridge(s) to specific single cartridge storage slots **16**.

Referring to FIGS. **9** and **2**, an embodiment of a method of storing data storage cartridges by an automated data storage library in accordance with the present invention comprises method **700** to destage data storage cartridges to multi-cartridge deep slot cells in conjunction with demount moves, demounting cartridges from data storage drive(s) **15**. Preferred moves are to the single cartridge storage slots **16**, called tier **0**. In method **700**, for moves from tier **0**, the library controller operates the accessor(s) to selectively extract a specific cartridge from its storage slot **16**, and transport the data storage cartridge with respect to other elements of the automated data storage library, for example, to a data storage drive **15**.

In accordance with the present invention, when a data storage cartridge is in a tier **0** single cartridge storage slot **16**, it is likely to have been received from a data storage drive and may be used again. Thus, it is preferable to extract data storage cartridges from tier **0** single cartridge storage slots **16** for moving to a data storage drive **15** and to demount and return the data storage cartridge to the same or another tier **0** storage slot, since a data storage cartridge, once used at a data storage drive, might be used more than once and would be readily available when in a tier **0** storage slot.

When the operation(s) at the data storage drive are complete, the controller, in steps **701** and **702**, will operate the accessor(s) to return the cartridge to an empty tier **0** storage slot, called a "floating home cell". If only one data storage cartridge is extracted from a tier **0** storage slot **16** and moved to a data storage drive **15**, and the other tier **0** storage slots are full, the home cell is the same storage slot from which it was extracted. If a number of data storage cartridges are extracted from tier **0** storage slots and moved to data storage drives, then those empty storage slots are each a floating home cell, and



## 11

each data storage cartridge is moved to the tier 0 storage slot 16 that is closest to the particular data storage drive 15 that the cartridge is demounted from.

All of the tier 0 single cartridge storage slots may be full because the cartridges mounted in the data storage drives are all from the multi-cartridge deep slot cells.

If all of the tier 0 single cartridge storage slots 16 are full, “NO” in step 701, at least in the particular frame of the library of the data storage drive 15 from which the data storage cartridge is demounted, the controller, in step 704, determines the cartridge in the selectively extracting, placing and transporting steps, to swap the data storage cartridge with a data storage cartridge in a tier 0 slot. In one embodiment, one choice may comprise selecting the least recently used (LRU) data storage cartridge in the storage slots (tier 0), for example, the cartridge having the longest time period since being unloaded from a data storage drive. Another choice in step 704 may comprise selecting a data storage cartridge that has a null usage timestamp, meaning that no timestamp was set for that cartridge. The swapped data storage cartridge is demoted to tier 1 of a multi-cartridge deep slot cell 100, in an action called “destage”.

Once the cartridge has been removed from the tier 0 slot, the demounted cartridge is moved to replace it in tier 0 in step 702.

The destage process is illustrated in steps 705 and 706 and comprises moving a cartridge to a multi-cartridge deep slot cell having at least one vacant tier. The destaged cartridge is inserted in the frontmost tier of a selected cell, and the other cartridge(s) in the cell, if any, are each demoted one tier within the cell.

Referring to step 707, in one embodiment, the library comprises multiple accessors, and at the time of demount of a cartridge, the library controller determines whether the second accessor is available. If so, “YES”, in step 708, the library controller operates the second accessor to extract the cartridge that was selected in step 704 from its storage slot. In step 709, the second accessor, which has the destaged cartridge, destages the cartridge to a multi-cartridge deep slot cell.

The first accessor in step 702 demounts the demounted cartridge from a data storage drive and places the cartridge in the tier 0 storage slot that was vacated by the destaged cartridge.

The use of two accessors, one to conduct a demount and the other to conduct a destage allows the demount to be conducted quickly, increasing the throughput at the data storage drive.

If the library has one accessor, or if step 707 determines that only one accessor is available, the one accessor must be operated to conduct the destage process of steps 705 and 706, and, when the process is complete, step 702 is conducted to demount and place the demounted cartridge in the storage slot vacated by the destaged cartridge.

FIG. 10 illustrates examples of placing data storage cartridges with respect to selected storage slots and multi-cartridge deep slot cells. The examples depicted in FIG. 10 are two dimensional arrays (or just one layer) used for ease of explanation. The same principals apply for three dimensional arrays of storage slots and multi-cartridge deep slot cells.

Referring to FIGS. 9 and 10, one example of a demount of a data storage cartridge “DM” from a data storage drive 15 begins at step 701 where the library controller determines whether any storage slot (tier 0) 16 is vacant. If one were vacant, the library controller would place the cartridge “DM” in the vacant storage slot.

## 12

In the example of FIG. 10, the storage slots 16 are full, and, in step 704, the library controller makes a selection of a cartridge to extract from a storage slot and to destage. One example of a basis for selecting a cartridge to extract is to select the cartridge that is least recently used of those in storage slots 16. For example, the least recently used cartridge may have the longest time period since it was demounted from a data storage drive 15. Other least recently used criteria may comprise the longest time since the cartridge was read, or the longest time since data was written to the cartridge.

Another example of a basis for selecting a cartridge to extract is to employ a timestamp applied to the cartridge, for example, by a data storage drive 15. The timestamp may be employed for the least recently used determination as well. The timestamp may be set to a “null” state by the drive 15 to indicate that the application requesting the cartridge will not be reaccessing the cartridge during the current processing of the application. Alternatively or additionally, cartridge may be newly inserted in the library and not have a timestamp, such that it is a “null”.

In the example, cartridge “E” in slot 720 is selected for extraction in step 704. In step 705 or in step 708, the selected cartridge “E” is extracted from storage slot 720 and destaged to a multi-cartridge deep slot cell 100 and inserted in tier 1, as shown by arrow 722. Insertion of cartridge “E” in tier 1 demotes the cartridge that was in tier 1, cartridge “A”, to tier 2. The demotion of cartridge “A” to tier 2 causes the demotion of cartridge “B” from tier 2 to tier 3.

Destaging cartridge “E” in step 705 or in step 708 vacates storage slot 720, and, in step 702, cartridge “DM” is demounted from a data storage drive and placed in vacated storage slot 720.

If there are no vacant storage slots, such that there are no available slots in the multi-cartridge deep slot cells 100 or the storage slots 16, the move is failed and the data storage cartridge may be ejected to an I/O station 24, 25.

The invention can take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment containing both hardware and software elements. In a preferred embodiment, the invention is implemented in software, which includes but is not limited to resident software, microcode, firmware, etc.

Furthermore, the invention can take the form of a computer program product accessible from a computer usable or computer readable medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer usable or computer readable medium can be any apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, and random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W) and DVD.

A data processing system suitable for storing and/or executing program code will include at least one processor coupled directly or indirectly to memory elements through a system bus, such as processor 400 of FIG. 4. The memory elements can include local memory employed during actual execution of the program code, such as nonvolatile memory 404 of FIG. 4, bulk storage, and cache memories which pro-



13

vide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

Those of skill in the art will understand that changes may be made with respect to the methods discussed above, including changes to the ordering of the choices of the methods of FIG. 9. Further, those of skill in the art will understand that differing specific component arrangements may be employed than those illustrated herein.

While the preferred embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and adaptations to those embodiments may occur to one skilled in the art without departing from the scope of the present invention as set forth in the following claims.

What is claimed is:

1. A method for operating an automated data storage library, said automated data storage library comprising at least a plurality of multi-cartridge deep slot cells, each configured to store up to a plurality of data storage cartridges arranged in sequential order of tiers from front to rear; a plurality of single cartridge storage slots, each configured to store a single data storage cartridge; and comprising a plurality of accessors, each configured to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots, said method comprising the steps of:

operating said accessors to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots, and with respect to other elements of said automated data storage library; and

in said selectively extracting, placing and transporting steps, if a data storage cartridge is recently used by a selected other element of said automated data storage library, and is to be demounted from said selected other element:

first, in said selectively extracting, placing and transporting steps, operating a first of said accessors extracting another data storage cartridge from said single cartridge storage slots, vacating one of said single cartridge storage slots, and destaging said extracted data storage cartridge to a multi-cartridge deep slot cell; and

second, in said selectively extracting, placing and transporting steps, extracting, operating a second of said accessors transporting and placing said demounted data storage cartridge in said vacated single cartridge storage slot, thereby swapping said demounted data storage cartridge with said extracted data storage cartridge.

2. An automated data storage library comprising:

at least a plurality of multi-cartridge deep slot cells, each configured to store up to a plurality of data storage cartridges arranged in sequential order of tiers from front to rear;

a plurality of single cartridge storage slots, each configured to store a single data storage cartridge;

a plurality of accessors, each configured to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots; and

a library controller configured to:

operate said accessors to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots, and with respect to other elements of said automated data storage library; and

14

in said selectively extracting, placing and transporting operation, if a data storage cartridge is recently used by a selected other element of said automated data storage library, and is to be demounted from said selected other element:

first, in said selectively extracting, placing and transporting operation, operating a first of said accessors to extract another data storage cartridge from said single cartridge storage slots, vacating one of said single cartridge storage slots, and destage said extracted data storage cartridge to a multi-cartridge deep slot cell; and

second, in said selectively extracting, placing and transporting operation, operating a second of said accessors to extract, transport and place said demounted data storage cartridge in said vacated single cartridge storage slot, thereby swapping said demounted data storage cartridge with said extracted data storage cartridge.

3. A computer program product embodied in a computer usable medium, said computer program product comprising a computer readable program when executed on a computer processor causes the computer processor to operate an automated data storage library, said automated data storage library comprising at least a plurality of multi-cartridge deep slot cells, each configured to store up to a plurality of data storage cartridges arranged in sequential order of tiers from front to rear; comprising a plurality of single cartridge storage slots, each configured to store a single data storage cartridge; and comprising a plurality of accessors, each configured to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots, said computer program product operating said automated data storage library via said computer processor in accordance with the steps of:

operating said accessors to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots, and with respect to other elements of said automated data storage library; and

in said selectively extracting, placing and transporting steps, if a data storage cartridge is recently used by a selected other element of said automated data storage library, and is to be demounted from said selected other element:

first, in said selectively extracting, placing and transporting steps, operating a first of said accessors to extract another data storage cartridge from said single cartridge storage slots, vacating one of said single cartridge storage slots, and destage said extracted data storage cartridge to a multi-cartridge deep slot cell; and

second, in said selectively extracting, placing and transporting steps, operating a second of said accessors to extract, transport and place said demounted data storage cartridge in said vacated single cartridge storage slot, thereby swapping said demounted data storage cartridge with said extracted data storage cartridge.

4. A library controller configured to operate an automated data storage library, said automated data storage library comprising at least a plurality of multi-cartridge deep slot cells, each configured to store up to a plurality of data storage cartridges arranged in sequential order of tiers from front to rear, a plurality of single cartridge storage slots, each configured to store a single data storage cartridge, and a plurality of accessors, each configured to selectively extract, place and transport data storage cartridges with respect to said multi-

**15**

cartridge deep slot cells and said single cartridge storage slots; said library controller comprising:

at least one computer processor configured in accordance with a computer program product to:

operate said accessors to selectively extract, place and transport data storage cartridges with respect to said multi-cartridge deep slot cells and said single cartridge storage slots, and with respect to other elements of said automated data storage library; and

in said selectively extracting, placing and transporting operation, if a data storage cartridge is recently used by a selected other element of said automated data storage library, and is to be demounted from said selected other element:

5  
10

**16**

first, in said selectively extracting, placing and transporting operation, operating a first of said accessors to extract another data storage cartridge from said single cartridge storage slots, vacating one of said single cartridge storage slots, and destage said extracted data storage cartridge to a multi-cartridge deep slot cell; and

second, in said selectively extracting, placing and transporting operation, operating a second of said accessors to extract, transport and place said demounted data storage cartridge in said vacated single cartridge storage slot, thereby swapping said demounted data storage cartridge with said extracted data storage cartridge.

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